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An efficient waste to energy model for isolated environments. Case study: La Gomera

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Abstract Municipal solid waste (MSW) management is a problematic aspect of isolated environments. Not only because the production of waste grows exponentially, but because in these isolated regions the difficulties are accentuated in comparison with the peninsular territories. The limitation of space, the technology of scale and the peaks of generation due to existing tourism, are clear examples of the barriers that must be overcome. This document studies the potential for the recovery of municipal solid waste on the island of La Gomera (Canary Islands) as an additional source of energy to produce heat and electricity. Also, the possibility of carrying out the landfill mining located in the El Revolcadero environmental complex is explored. Many advantages are derived from this model: there is a significant increase in the fraction of recycling (almost non-existent at present), a greater share of renewable energy on the island (most installed capacity is diesel), the recovery of green areas and a reduction of greenhouse gases (GHG). To overcome the challenges that lie ahead in the integral management of MSW, it is necessary to move from a linear economy to a circular economy that takes into account the priorities established by the European Union to improve the collection and treatment of municipal waste.

Keywords: waste to energy; isolated electricity system; circular economy; waste management; Canary Islands

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1 Introduction

Landfills are one of the most important sources of gaseous emissions. These emissions are known to contain mainly methane (CH_4) and carbon dioxide (CO_2), both considered greenhouse gases that contribute to global warming (Jönsson et al., 2003). The amount of municipal solid waste (MSW) generated each year and the numerous actors and bodies involved in this complex process are issues that require detailed study, to propose effective practical measures to improve their management. Cities are undergoing a critical situation owing to the increasing amount of solid waste they generate and the resulting incessant demand for new sites for final disposal. In view of this situation, diverse treatment technologies continue to be evaluated (Greenpace, 2011; Filho et al., 2016; Scarlat et al., 2015).

Furthermore, the generation of electricity, heat or biofuels from renewable energy sources has become a priority in energy policy strategies on a global scale (Amigun et al., 2011). According to Nijkamp and Kourtit (2013), cities consume 75% of the energy produced worldwide and generate 80% of CO_2 emissions; so it makes sense to try to reduce the emission of gases from residues by using them to generate energy. In this context, waste has been identified as an environmentally friendly energy source. Its utilization is considered an effective method to reduce the total emission of gases into the environment (El Hanandeh and El Zein, 2011). Seen in this way, the waste to energy (WtE) concept encapsulates an excellent opportunity to face two important current problems: on the one hand, the generation of energy from less polluting sources and, on the other, the valorization of solid waste that otherwise accumulates in expensive landfills.

2 The management of municipal solid waste in La Gomera

La Gomera is located approximately 28 km from the west coast of the island of Tenerife. It has an area of 369 km^2, making it the third smallest inhabited island in the Canary archipelago after El Hierro and La Graciosa. The Master Plan for waste management on the island is obsolete (PDGR, 1982). This plan is awaiting an update that to date has not materialized. Few islands in the Canary archipelago have an updated waste plan. Meanwhile, the islands resort to the Canary Islands Comprehensive Waste Plan, approved by Decree 161/2001 (BOC, 2001).

Waste collection forecasts estimate low quantities to propose a processing plan that requires costly and complicated treatment. Based on the data collected and the publications available (GOBCAN, 2010), the total amount of bulk refuse classifiable as MSW produced on La Gomera is close to 9,709 tons per year. The management system is based on simple removal of these quantities to landfill sites. From the energy and environmental point of view, this solution can be vastly improved. In addition, the quantities destined to recycling are minimal or symbolic because the selective collection system on the island is underdeveloped.

La Gomera has ten waste-disposal sites. Five dumping areas for uncontrolled urban waste (one of them abandoned more than ten years ago), an uncontrolled inert landfill, three centres for storing scrap metal, a "clean point" recycling depot (in the capital, San Sebastián) and an environmental complex. This facility is located within the municipal district of San Sebastián, in the Revolcadero ravine. It has an impermeabilized base. However, the major problem is that it is close to overflowing, due to the absence of efficient waste prevention and management policies.

3 Approach, data and methodology

In Figure 1, a description of the proposed model is provided. In addition to the island being thus able to comprehensively manage its waste, the aim is to reduce the surface area occupied by the landfill by almost 90%. In this way, repopulation and soil treatment work and landscaping can facilitate the environmental recovery of the area. This, without doubt, will contribute to the restoration of the native ecosystems with the introduction of local flora and fauna in order to reintegrate the landfill area into the landscape.

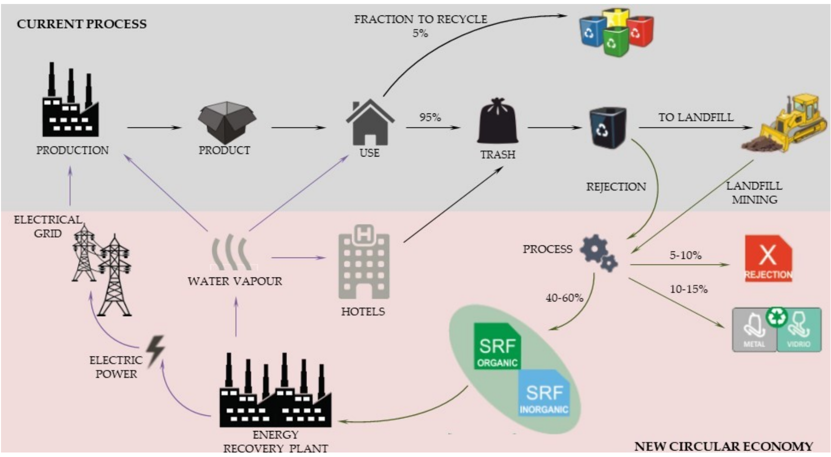

Fig. 1 Flow diagram of the waste energy recovery process proposed for La Gomera

3.1 Population data

In Table 1, the population projection of the island of La Gomera 2016-2025 is shown.

Table 1 Population projection of the island of La Gomera 2016-2025 (thousands of inhabitants)

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Population	26,908	27,340	27,776	28,211	28,641	29,078	29,510	29,938	30,369	30,794

3.2 Characterization of island waste

The last official update on the composition and characterization of MSW in the Canary Islands was provided by their autonomous government (GOBCAN, 2010). The authors rely on this study to better understand the management options and potential waste treatments on the island of La Gomera. Regarding the sampling quantities, from trucks and loaders, representative samples were obtained whose weight ranged between 200 and 300 kg. For each sample, a tally register file and data tables were established and completed. Thus, on La Gomera, six significant samples were taken (one for each municipality). Of these samples, 32.4% was the organic fraction and 40.2% the rest of the waste that is not classified as packaging (plastics, glass, iron, etc.). These data are important to redesign waste management at the island level.

3.3 Methodology

The estimates offered in this study consider the production and collection of urban solid waste from the island of La Gomera. Considering the data available from the Canary Islands government and the island council of La Gomera (Cabildo) mentioned above, the aim is to estimate: 1) uncontrolled emissions (without any gas collection and control system), methane and carbon dioxide in the landfill; 2) the amount of energy that can be produced through the use of urban solid waste; and, finally, 3) the savings produced in this type of isolated system.

3.3.1 Calculation of landfill emissions

The theoretical model we apply to calculate CH_4 and CO_2 emissions in a landfill with uncontrolled emissions is based on the following first-order kinetic equation:

$$Q_{CH4} = L_o \cdot R \cdot (e^{-kC} - e^{-kt}) \qquad (3.1)$$

Where: Q_{CH4} is the amount of methane at time t (Tn / year); Lo is the methane generation potential (Tn Q_{CH4} / Tn waste); R is the annual average of solid waste (Tn waste / year); k is the ratio of methane generation (1/year); C is the time since the closure of the dump or landfill (years); t is the number of years since the first load deposited. Additionally, to calculate Lo the following formula is applied:

$$L_o = DOC \cdot DOCf \cdot s \cdot F \cdot MCF \qquad (3.2)$$

Where: DOC is the fraction of degradable organic carbon in the refuse (dimensionless); DOCf is the portion of DOC converted to landfill gas (dimensionless); s takes the value of 16/12 (stoichiometric factor to convert carbon to CH_4, dimensionless); F is the fraction of CH_4 in the landfill gas (dimensionless); MCF is the methane correction factor indicating the amount of methane in landfill gas (dimensionless). In this case, unity is assumed as its value (one managed landfill). In this study, a default DOCf value of 0.5 was considered, as recommended by the IPCC based on several experimental studies (IPCC, 2002, 2006) as is the value 0.5 assumed for the methane fraction in landfill gas (F).

Since not all organic matter can be decomposed, the DOC fraction considers the fraction of organic carbon accessible to biochemical decomposition, depending on the content of the waste, which varies according to its place of origin (Kumar et al., 2004). This study takes into account the variability of the data on this, as well as its possible range. The DOC is expressed in equation (3.3) and is essential to calculate methane generation.

$$DOC = 0.4 \cdot A + 0.17 \cdot B + 0.15 \cdot C + 0.30 \cdot D \qquad (3.3)$$

Where A is the proportion of carbon in the paper, cardboard and textile content (%); B is the carbon corresponding to putrescible organic waste from gardens, parks etc., except food (%); C is the carbon in food waste (%); D is the carbon in wood and straw waste (%).

3.3.2 Estimation of the energy generated by the waste stream

The last estimated volume occupied by MSW was 227,500 m^3. An average density for this waste of about 650 kg/m^3 was assumed for the present study. In addition, according to the studies of recyclable waste in the landfill of La Gomera, and also the technologist with whom the estimation model was constructed (Greene, 2015), it is estimated that this facility contains about 40% soil-type material, 40% suitable for fuel, between 10-15% that can be recycled (metals and glass) and 5-10% to be rejected. On the other hand, the model must consider technological limitations, especially in an isolated environment such as the Canary Islands, where it is necessary to adapt the existing technology to smaller streams than mainland territories.

4 A waste model for La Gomera: opportunities

In Figure 1, a description of the proposed scheme is provided. In addition to the island being thus able to comprehensively manage its waste, the aim is to reduce the surface area occupied by the landfill by almost 90%. In this way, repopulation and soil treatment work and landscaping can facilitate the environmental recovery of the area. This, without a doubt, will contribute to the restoration of the native ecosystems with the introduction of local flora and fauna for reintegrating the landfill area into the landscape.

5 Results

In view of the above, although it is necessary to accept the inaccuracies of the model, the results certainly encourage further studies to optimize waste management. A quantity of 147,875 Tn could be considered the landfill waste for annual use. However, this amount should be deducted from the high proportion of soil and aggregates that it also contains. Figure 2 shows that waste valorization permits better recycling figures than those achieved with the previous management policies.

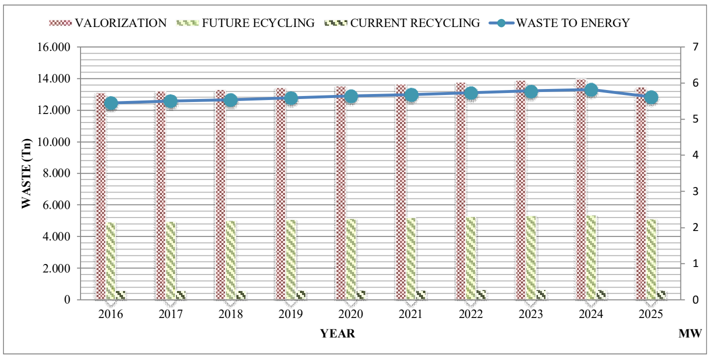

Fig. 2 Valorization and Recycling levels for the horizon 2016-2025

Finally, Figure 3 shows the emissions of CH_4 and CO_2 within the proposed horizon that would be avoided by landfill mining. That is, the figures shown correspond to what the MSW collected and landfilled in the current situation would generate annually.

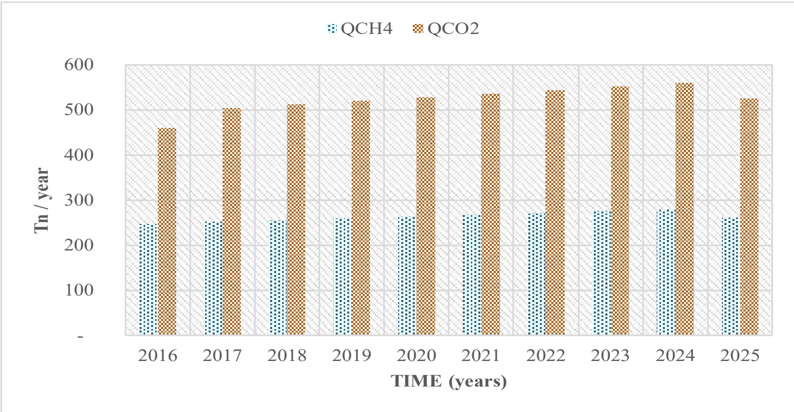

Fig. 3 Projected evolution of CO_2 and CH_4 emissions on the island of La Gomera 2016-2025

6. Conclusions

The limiting characteristics of the territory greatly impede the activities of collection, transport, storage, treatment and disposal of waste and involve high management costs, aggravated by the need to transport the waste to and from remote areas. The common problems in isolated territories are the following: the small number of facilities for treatment or elimination, the impact of tourism on the local waste management plan, the limited space available to locate landfills and their rapid filling, and the difficulty of achieving economies of scale.

On the other hand, it is vital to implement waste policies that are aimed at not only improving the integral management of MSW but to urgently set goals that have been delayed for many years. These targets will contribute to improving and materializing the concept of sustainability in these environments. In this sense, the insularity of urban waste management (collection, transport, treatment, recycling and disposal), recovery of hazardous materials from municipal waste, recovery and valorization of those waste fractions feasible from a unified technical, economic and environmental perspective, implementation of communication and training campaigns, etc., are all pending issues that must not be forgotten. All this would be more effective if sustainability were understood as the key from the very beginning of the production chain (sustainable design). In this way, besides Waste to Energy (WtE), there would be also Waste to Material (WtM) type solutions.

Within this landfill-mining concept, we must point out that materials recovered deposited in landfills should be grouped for later reuse as secondary materials, and if impossible, their energy recovery. Specific examples are the scrap and precious metals obtained from the process. These have a lower market value than in their new unused state, especially in the case of those most sensitive to degradation. However, the local recovery of these materials would to a certain degree alleviate the heavy cost of exporting them and importing new raw materials.

Finally, the authors have tried to put forward a solution that takes into account the circular economy model as a self-regenerative system in which the input of waste resources and emissions and energy losses are minimized by slowing, closing and reducing the material and energy loops. It is obvious that the road is still arduous and that isolated environments are still behind continental systems, but at this point, it is essential to propose studies and measures that encourage awareness and action.

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